# Estimating Canopy Water Content of Chaparral Shrubs using optical Methods

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California chaparral ecosystems are exceptionally fire adapted and typically arc subject to wildfire at decadal to century frequencies. The hot dry Mediterranean climate summers and the chaparral communities of the Santa Monica Mountains make wildfire onc of the most serious economic and life-threatening natural disasters faced by the region. Additionally, the steep fire-burned hillsides arc subject to erosion, slumpage, and mud slides during the winter rains. The Santa Monica Mountain Zone (SMMZ) is a 104,000 ha east-west trending range with 607 m of vertical relief and located in the center of the greater Los Angeles region. A series of fires in the fall of 1993 burned from Simi Valley to Santa Monica within a fcw hours. Developing techniques to monitor fire hazard and predict the spread of fire is of major concern to the region. Onc key factor in the susceptibility to fire is the water content of the vegetation canopy. The development of imaging spectrometry and remote sensing techniques may constitute a tool to provide this information.

At least four distinct chaparral communities exist in the mountains which arc found in a complex spatial mosaic across this range. These species exhibit different sensitivities to fire and responses to post-fire because of differences in their growth patterns, density, biomass and litter accumulations, and water contents, These shrub communities are known as chamise chaparral (often nearly pure stands of *Adenostoma fasciculatum*). *Ceanothus* chaparral, which is typically mid-successional and is dominated by one or more species of *Ceanothus* (California lilac). Broadleaf chaparral, which is generally the most diverse, is often composed of several shrub species. 1 astly, the coastal region may bc dominated by Coastal sage (*Salvia*) species. This latter community tends to maintain the highest foliar density and is greenest to the eye.

We obtained spectral measurements in the field (ASD-2500nm range) and the lab (CARY 5E) on the dominant chaparral species at canopy and leaf scales and compared these to estimates of water content in concurrent] y acquired AVIRIS images in June and October, 1995 to examine how well variation in canopy water contents can be estimated using optical sensors. Measurements were made at three sites, Zuma Ridge, Castro Crest and Encino Reservoir, which were chosen as representative of the dominant communities and presenting plants of the major species in different stages of growth. The three sites arc Zuma Ridge, a coastal site with young sage and mixed chaparral vegetation, Castro Crest, a mountain site with medium above ground biomass accumulation and mixed chaparral vegetation, and Encino Reservoir, an inland site on the eastern edge of the reservoir with old growth *Ceanothus* vegetation, with high biomass chaparral shrubs, 3 to 4 meters tall. The Forest Service Fire Lab and the Los Angeles County Fire District harvested above ground canopy biomass from 15 5m x 5m plots. Total plot biomass was weighed in the field. A subsample of the biomass was measured for water content, leaf mass and stem mass (in different stcm size categories) for the June data acquisition. The ASD spectrometer was mounted on a bucket truck and above canopy spectra were acquired at the three sites, Water content was estimated for the canopy within the field of view of the ASD. The following species were recorded at these sites:

Table 1. Species found at the three sites,

Zuma: MALA, ARCA, SALE, ERAR
Castro: ADFA, CEOL, ARGL
Encino: CEME, and DRY GRASS

| Acronym | Latin name | Family | Common name |
|---|---|---|---|
| MALA | Rhus laurina | Anacardiaceae | Laurel Sumac |
| ARCA | Artemisia californica | Asteraceae | Coastal Sagebrush |
| SALE | Salvia leucophylla | Lamiaceae | Purple Sage |
| ERAR | Eriogonum cinereum | Polygonaceae | Ashy Leaf Buckwheat |
| ADFA | Adenostoma fasciculatum | | Chamise, Greasewood |
| CEOL | Ceanothus oliganthus | Rhamnaceae | Hairy-leaf Ceanothus |
| ARGL | Arctostaphylos . glandulosa | Ericaceae | Eastwood Manzanita |
| CEME | Ceanothus megacarpus | | Big Pod Ceanothus |

Methods
Field Radiometric Data
    For all three sites, seven locations were chosen from above the canopy in the bucket truck for the radiometric measurements. Species, canopy height, and spectrometer height were recorded. A Spectralon panel was mounted on a tripod attached to the bucket and adjusted normal to the ground using a leveling device taped to the corner of the standard for calibrating to surface reflectance. Corrections for Spectralon were post-processed to produce absolute 100% reflectance.

Laboratory Radiometric Data
    For most of the species, both leaf reflectance and transmittance were measured in the lab on a CARY 5E spectrophotometer with a 150mm Labsphere Integrating sphere with a Spectralon surface. The wavelengths range from 400 nm to 2500 nm with an interval of 2 nm. We acquired reflectance spectra for all the species; for ADFA and ARCA which have needle-like leaves, the transmittance could not be measured so only the infinite reflectance of an optically thick sample was obtained,

Laboratory biophysical Measurements
    Some samples of fresh leaves, stems and flowers were collected in the field to calculate water content. For large plant leaves, the fresh weight of 3.46 $cm^2$ disks measured, which were cut using a cork borer and immediately weighed using a portable electronic balance; for small leaves, we weighed entire blades, the area of which was later measured using a Canon Video Visualizer RE-650 camera and a digitizer. The stems and flowers of some plants were also processed. All the samples were dried at 70"C for four days before dry weights were measured. Assuming that FW is the fresh weight, DW the dry weight, and S the leaf area, water content (WC) was calculated, the equivalent water thickness (EWT), the leaf specific weight (LSW) and the specific leaf area (S1.A) which is the reciprocal of the leaf specific weight:

$$WC = \frac{FW - DW}{FW} \qquad EWT = \frac{FW - DW}{S} \qquad LSW = \frac{1}{SLA} = \frac{DW}{S}$$

WC is the water mass over fresh mass, EWT and 1.S W are respectively the water and dry matter masses per unit leaf area, expressed in $g.cm^{-2}$; in consequence, the S1.A is provided in $cm^2.g^{-1}$.

**Data** Analysis

Three methods for estimating canopy water content were applied to the laboratory and field data sets. The first method applied a modified version of the PROSPECT model (Jacquemoud et al., 1996), which predicts several leaf chemistry variables including water thickness from the reflectance data. The second method used a continuum removal technique to fit a curve to the water absorption feature (Clark and Rosh, 1984). The third method used a new technique, termed by Smith et al. (1994) Foreground/Background Analysis (FBA). In a modified form described by Pinzon et al. (1995, 1996), FBA relates optical properties to canopy biochemical concentrations in three steps. First, the Gram-Smith orthogonal ization procedure was used to extract the bands that explain most of the spectra] variation for water absorption. Second, the samples were stratified into different reflectance ranges by defining a FBA vector that permits their hierarchical classification. Finally, FBA was used to find new vectors that best relates leaf reflectance to water content, These results from each of these methods were compared for accuracy of the assessment and all three methods gave reasonably good predictions at the leaf and canopy levels. The significance of differences among the methods will be discussed. The methods were then applied to the calibrated AVIRIS datasets from June 1995 and spatial estimates of above ground canopy water contents were obtained,

Table 2. Leaf biophysical measurements predicted by the PROSPECT model. Leaf thickness, pigment content and water content arc estimated from 40 fresh leaves measured in the CARY spectroradiometer from this experiment.

| Variable | Unit | Range | Mean | S t d. Dev |
|---|---|---|---|---|
| leaf thickness | mm | 86.4 -780,0 | 194.5 | 114.9 |
| SLA | crn2 g-1 | 73.9-535.3 | 224.6 | 93.4 |
| Water Content | %Fresh Wt. | 44.9 -92.4 | 66.4 | 11.0 |
| Water Concentration | g cm-2 | 0.0046-0.0405 | | |
| Chlorophyll $\alpha$ | µg cm-2 | 12.8 -64.2 | 36.9 | 11.4 |
| Chlorophyll $\beta$ | µg cm-2 | 3.7-21.3 | 11.7 | 3.8 |
| Carotenes | µg cm-2 | 3.7-19.4 | 10.5 | 3.6 |
| Celllulose | %Dry wt. | 9.1-37.2 | 19.7 | 6.4 |
| Cellulose | g cm-2 | 0.00031-0.00545 | | |
| Hemicellulose | % Dry wt. | 0.3-38.8 | 15.2 | 10.0 |
| | g cm-2 | 0.00002-0.00332 | | |
| Lignin | % Dry wt. | 1.1-27.5 | 10.2 | **6.4** |
| | g cm-2 | **0.00003-0.00305** | | |
| Protein | %Dry wt. | 7.4-36.8 | 20.0 | 7.0 |
| | g cm-2 | 0.00048-0.00172 | | |
| Starch | % Dry Wt. | 0.0-10,0 | 2.0 | **2.1** |
| | g cm-2 | 0.0000-0.00098 | | |
| Total Carbon | % Dry w t . | 38.5 -52.3 | 47.4 | 2.9 |
| | g cm-2 | 0.00079-0.00665 | | |
| Total Nitrogen | % Dry wt. | 1.2-5.9 | 3.4 | 1.1 |
| | g cm-2 | 0.00009-0.00033 | | |

An example of the results of the PROSPECT model run arc shown in Figure 1a for onc random] y selected leaf from the dataset. The predicted and measured liquid water estimates for **40** leaf samples measured on the CARY spectrometer in the lab are shown in Figure lb. A summary of the predicted foliar biochemical composition from the Cary laboratory spectra for the 40 leaf samples is shown in Table 2. The results of the three leaf and canopy spectral analysis methods were compared to equivalent path leaf water thickness estimates obtained from the atmospheric calibration of AVIRIS data obtained using the method of Green ct al. (1995). These results were also compared to the field measured canopy water content and biomass data provided by the Forest Service. Results support the usc of AVIRIS image analysis techniques for estimating spatial variation in water content,

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Figure 1a (left) shows the fit bctwccn the measured leaf reflectance and transmission using the revised PROSPECT model. Figure 1b (right) shows the predictcd and measured liquid water estimates $(g.cm^{-2})$ for 40 lcaf samplcs of various chaparral shrub species that were measured on the CARY spectrometer.



N-1 766 Cabx=46.58 Cw=0 02286 Pro=1e-06 Cel+Lig=0 005265

Prospect Liquid Water vs Lopex93